TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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FLIGHT TESTS TO DETERMINE THE EFFECT OF A FIXED AUXILIARY AIRFOIL ON THE LIFT AND DRAG OF A PARASOL MONOPLANE

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SUMMARY

During an investigation in the N.A.C.A. vertical wind tunnel of means of increasing the speed range of airplanes, a combination of a fixed auxiliary airfoil and wing was found that gave results comparable with those obtained with automatic slots. In order to verify these results, comparative flight tests were made with a small parasol monoplane in which the aerodynamic characteristics of the airplane were determined with the normal wing and with an auxiliary airfoil installed.

The results of these tests showed that the maximum lift coefficient of the airplane, based on the original wing area, was increased from 1.35 to 1.96, through the use of the auxiliary airfoil, while the minimum drag was increased from 0.050 to 0.052. Although the actual values of the coefficients do not check the wind-tunnel results, the percentage increases in the coefficients are in fair agreement. The installation of the auxiliary airfoil on the airplane tested decreased the landing speed 9 miles per hour, and increased the level-flight speed range 10 per cent.

INTRODUCTION

In connection with its program leading to greater safety in landing, the National Advisory Committee for Aeronautics is conducting an investigation of devices for increasing airplane speed ranges by increasing the ratio $\frac{C_{Lmax}}{C_{Dmin}}$ of the wings. Special attention is being directed to devices having no moving parts, consequently being free from the possibility of mechanical trouble.

A series of tests recently made in the vertical tunnel showed that promising results could be obtained with a fixed auxiliary airfoil (fig. 1) mounted above and ahead of the main wing. (Reference 1.) Before proceeding further with the wind-tunnel tests, it was thought desirable to test the best arrangement of the wing and auxiliary airfoil found to date in flight, to make certain that the comparisons made in reference 1 were not invalidated by a difference in scale effect on the normal wing and on the wing with the auxiliary airfoil installed.

This paper presents the results of the flight tests. The tests were made with a small parasol monoplane. Its aerodynamic characteristics were measured with the normal wing and with an installation of an auxiliary airfoil corresponding to the best arrangement given in reference 1. With both wing conditions, the characteristics were measured from the angle of attack of minimum drag to the highest angle of attack at which the control was adequate for maintaining steady conditions. Computations were made to show the effect of the auxiliary airfoil on the performance of the airplane.

APPARATUS AND METHOD

The airplane used in the flight tests was the Fairchild 22, a small parasol monoplane. Its principal dimensions are given on Figure 2. It is fitted with a wing having the N-22 airfoil section, a span of 32 feet 10 inches, a chord of 66 inches, and an area of 171 square feet.

It would have been more desirable to have tested the auxiliary airfoil in conjunction with a wing having a Clark Y section, the Clark Y section having been used in the tests of reference 1. However, an airplane with a Clark Y wing was not available. The feasibility of constructing such a wing for the Fairchild 22 was considered, but because of the similarity of the characteristics of the Clark Y and N-22 sections, and the probability that the effect of the auxiliary airfoil would be similar with either section, the extra time required for building a new wing was thought unwarranted.

The dimensions and arrangement of the auxiliary airfoil are shown in Figure 1. The airfoil section was the same as that used in the wind-tunnel tests, and the location was the optimum found in those tests. The auxiliary airfoil had a span of 30 feet, a chord of 10 inches (15.2 per cent c, where c is the chord length of the main wing), and an area of 25 square feet (14.6 per cent of the main wing area). It was located so that its trailing edge was 10 inches (15.2 per cent c) ahead of the nose of the main wing and its chord line was 9 inches (13.6 per cent c) above and parallel to the main wing chord.

The auxiliary airfoil was constructed of laminated spruce and had a duralumin trailing edge. It was attached to the lower surface of the main wing by nine steel tubes (fig. 3), one at each drag strut. No attempt was made to save weight in the design, as the additional weight helped to maintain the proper relation between the center of pressure and center of gravity for satisfactory balance in flight, and also because the distribution of forces between the auxiliary airfoil and main wing was unknown. The total increase in weight due to the installation of the auxiliary airfoil was approximately 130 pounds.

The tests of reference 1 showed that the addition of the auxiliary airfoil would move the center of pressure forward a considerable distance, and indicated thereby that it would be necessary to move the center of gravity of the airplane forward. The required change in the center of gravity of the airplane was found by trial. With the original wing, satisfactory balance was attained with the center of gravity at 30.9 per cent of the wing chord. With the auxiliary airfoil installed, the center of gravity was shifted forward to 27.1 per cent of the main wing chord to attain satisfactory balance.

The aerodynamic characteristics of the airplane were found by gliding with the propeller stopped and measuring the angle of the flight path, the attitude of the airplane (propeller axis), and the dynamic pressure during the glide. The flight-path angle and dynamic pressure were measured with a photographic recording instrument (reference 2) suspended 90 feet below the airplane where the influence of the wing on the flow was negligible. A recording inclinometer was used to determine the airplane's attitude. From the weight of the airplane at the time of the flight and the flight-path angle, the total lift and drag forces were found. The drag of the suspended instrument had been determined (reference 3) and a correction for it was applied to the drag forces. The lift and drag forces were then reduced to coefficient form through the introduction of the dynamic pressure and wing area. The angle of attack was obtained from the difference between the flight path and attitude angles. The range of angles of attack covered was from -3° for both wing conditions to 16° for the normal wing, and to 28° for the wing and auxiliary airfoil.

During the glides the propeller was always stopped in a vertical position by means of a brake fitted to the hub and operated by the pilot. On completion of the flight tests the drag of the propeller was determined in the full-scale wind tunnel. The drag coefficient of the propeller when based on the wing area was found to have a practically constant value of 0.008 for all angles of attack and for both wing conditions. This value was used in deducing results for the airplane without propeller.

RESULTS

The final results of the tests are presented in graphical form in Figures 4 to 9, inclusive. Figure 4 shows the aerodynamic characteristics of the airplane with the normal N-22 wing. The experimental points are shown and no correction is made for the propeller drag. Figure 5 gives similar data for the airplane fitted with the auxiliary airfoil. The data of the figures are based on the main wing area. Figures 6 and 7 are comparative curves of the results for the two wing conditions after a correction has been made for the propeller drag. Figure 6 is based on the main wing area only, while Figure 7 is based on the actual areas.

In order to show more clearly the effect of the installation of the auxiliary airfoil on the performance characteristics of this particular airplane, Figures 8 and 9 have been included. Figure 8 is a velocity diagram and Figure 9 is a plot of the comparative performance curves. The horsepower-available curve of Figure 9 is only approximate, being computed from estimated propeller and engine characteristics. Figure 8 is based on the data of Figures 4 and 5 for the stopped propeller condition. In Figures 8 and 9 the gross weight of the airplane for the normal wing was taken as 1,500 pounds. For the wing and auxiliary airfoil, allowance was made for the probable increase of weight caused by a reasonably well-designed installation of the auxiliary airfoil as an integral part of the wing. This allowance was 60 pounds, and was arrived at on the assumption that the projected area of the wing and auxiliary airfoil would have the same unit weight as the wing alone.

PRECISION

The precision with which the aerodynamic characteristics can be determined by glide tests was established during previous tests. (Reference 3.) As the present tests were conducted in a similar manner to the previous ones and with the same instruments, it is very probable the same degree of precision was attained. The limits of precision as given in reference 3 are: for the lift curves, ±2 per cent; for the drag curves, ±3 per cent; and for the angles of attack, ±0.3°.

DISCUSSION

In a comparison of the aerodynamic characteristics of the Fairchild 22 airplane with the normal N-22 wing and with the auxiliary airfoil installed, there are several items of particular interest. These are: the maximum lift coefficient, the minimum drag coefficient, the speed-range criterion $\frac{C_{L_{max}}}{C_{D_{min}}}$, and the maximum L/D ratio. A direct comparison of these items can be made by reference to Figure 6 where the results with the two wing conditions have been calculated on the basis of the main wing area only.

Figure 6 shows that for the normal wing the maximum lift coefficient is 1.35, the minimum drag coefficient 0.050, and maximum L/D 9.3. With the auxiliary airfoil installed, the values are 2.03, 0.052, and 9.3, respectively. Computations give the speed-range criterion as 27 for the normal wing, and 39 for the wing and auxiliary airfoil. Before proceeding further with the comparison of the two wing conditions, it is necessary to note the peculiarity of the lift curve for the airplane with the auxiliary airfoil at high angles of attack. This peculiarity is shown on

Figure 6 by the two distinct lift curves above an angle of attack of 24°, and is evidenced in flight during a steady glide by an abrupt change in the attitude of the airplane, after which there is no tendency to oscillate longitudinally and the ensuing glide is as steady as that before the change. Because of this phenomenon, it is considered unsafe to exceed an angle of attack of 24°, particularly in landing. At 24° the lift coefficient is 1.96, and comparisons will be made with this practical value for the lift coefficient except in certain specific cases, which will be noted. On this basis, the speed-range criterion is 38. Through use of the auxiliary airfoil, the maximum lift coefficient and the speed-range criterion were increased 45 per cent and 40 per cent, respectively, while the minimum drag coefficient was increased only 4 per cent and the maximum L/D remained unchanged.

In the usual case, the drag of an airplane wing constitutes only a small proportion of the total airplane drag at low angles of attack. The relative proportions of the wing drag and total drag vary considerably for different airplanes. Consequently, for a more general application of the test results it is necessary to consider the effect of the auxiliary airfoil on the wing alone. As it was impossible to determine the drag of the wing alone from glide-test data, the value 0.011 was taken for the minimum drag coefficient for the N-22 wing from the variable-density tunnel measurements reported in reference 4. On the basis of this drag coefficient the speed-range criterion for the normal wing is 123. The difference in the minimum drag coefficients for the two wing conditions is attributed to the effect of the auxiliary airfoil on the wing drag only. The minimum drag coefficient of the wing and auxiliary airfoil is then 0.013, and the speed-range criterion 151. These values represent increases of 18 per cent and 23 per cent, respectively, over the corresponding values for the wing alone.

As was expected, the actual values for the various items under consideration from the flight tests do not agree with those from the wind-tunnel tests given in reference 1. Therefore the comparison of the flight and tunnel results is made on the basis of the percentage increases obtained through the use of the auxiliary airfoil. For this comparison, the absolute value 2.03 is used for the maximum lift coefficient for the wing and auxiliary airfoil instead of the practical value 1.96. On this basis, the increases shown by the flight tests are: for the maximum lift coefficient, 51 per cent; for the minimum drag coefficient, 18 per cent; and for the speed-range criterion, 23 per cent. Reference 1 gives corresponding values of 51 per cent, 25 per cent, and 21 per cent. The agreement is satisfactory.

The above comparisons show only the effect of the auxiliary airfoil on the characteristics of a given wing. It may be desired to compare the wing with auxiliary airfoil with other wing sections and high lift combinations. In order to permit such a comparison, the coefficients for the wing with auxiliary airfoil have been computed on the basis of the actual areas of the combination and plotted in Figure 7. The maximum lift coefficient on this basis is 1.71 instead of 1.96. However, there is a proportionate decrease in the minimum drag coefficient so that the speed-range criterion remains unchanged. Judgment should be exercised in comparing the maximum lift coefficient of the wing-auxiliary-airfoil combination with that for a plain wing, as it is possible to construct a solid wing with a chord equal to the over-all chord of the combination of the same weight as the combination. For this reason, the speed-range criterion probably is a better basis than maximum lift coefficient when comparing the wing with auxiliary airfoil with plain wings having reasonably high values for maximum lift coefficients. It is also well to note in this connection that the small center-of-pressure travel for the wing and auxiliary airfoil shown by the wind-tunnel tests is an advantage not to be ignored in a comparison of the device with other wing sections.

The improvement to the performance of the Fairchild 22 airplane gained through the use of the auxiliary airfoil is shown in Figures 8 and 9. Of particular note on Figure 8 is the decrease of 9 miles per hour in the landing speed for the airplane with the auxiliary airfoil installed. Also of interest is the fact that although the minimum gliding angles are identical, 6.6°, for the two wing conditions, the angle of glide for the wing and auxiliary airfoil at 24° angle of attack is 17.1°, whereas at the stalling angle of the normal wing the gliding angle is only 8.6°. In fact, at the highest angle of attack attained for the normal wing, 2° beyond the stall, the angle of glide is 13.1°, which is still 3.7° below the unstalled glide of the wing and auxiliary airfoil. It is interesting to note in connection with this consideration of gliding angles that from a point at an altitude of 100 feet the airplane with the auxiliary airfoil could be landed without stalling from 326 feet to 860 feet horizontal distance from the point. Without the auxiliary airfoil the landing range would be from 660 feet to 860 feet. Figure 8 also shows that if an angle of attack of 24° was exceeded with the wing and auxiliary airfoil, the vertical velocity would be likely to increase suddenly 220 feet per minute because of the previously mentioned peculiarity in the lift curve.

Figure 9 shows that although the high speed is decreased 1.7 miles per hour through the use of the auxiliary airfoil, the low speed in level flight is decreased 5.0 miles per hour, resulting in a 10 per cent increase in speed range. It is interesting to note that the high drag at large angles of attack, although an advantage in increasing the gliding angle when landing, is a disadvantage at take-off in that the power required at maximum lift is considerably in excess of that available. The actual take-off must be made at a lift coefficient of 1.75 instead of 1.96, and consequently the actual take-off speed is 3 miles per hour greater than the potential take-off speed. The high drag at large angles of attack is inherent in most high-lift devices, and the feasibility of installing controllable-pitch propellers in conjunction with such devices should be considered. The maximum rates of climb for the two conditions are not greatly different, being 580 feet per minute with the normal wing and 550 feet per minute with the auxiliary airfoil installed. It appears, also, that the auxiliary airfoil reduces the maximum angle of climb from 6.2° to 5.3° and the absolute ceiling from 14,000 feet to 12,000 feet. It should be borne in mind that these figures are based on an assumed horsepower available curve and are not intended to represent the actual performance of the airplane.

The satisfactory results obtained with the auxiliary airfoil of the Fairchild 22 airplane show its possibilities and the desirability of continuing the wind-tunnel tests. Tests should be made of the device in its final form to determine the distribution of forces between the airfoil and main wing so that rational stress analyses can be made for future installations.

CONCLUSIONS

1. The maximum practical lift coefficient of the Fairchild 22 airplane, based on the main wing area only, was increased from 1.35 to 1.96 by use of an auxiliary airfoil, while the minimum drag coefficient was only increased from 0.050 to 0.052, and the maximum L/D was not appreciably affected.

2. The percentage increase in maximum lift coefficient of 51 per cent found by the flight tests is in agreement with that found in the tests of the auxiliary airfoil in the vertical wind tunnel in which the auxiliary airfoil was in approximately the same position relative to the main wing.

3. For the wing alone, the ratio $\frac{C_{L_{max}}}{C_{D_{min}}}$ was increased from 123 to 151 by the installation of the auxiliary airfoil.

4. The installation of the auxiliary airfoil on the Fairchild 22 airplane caused a decrease of 9 miles per hour in landing speed and an increase of 10 per cent in the level-flight speed range.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., October 25, 1932.

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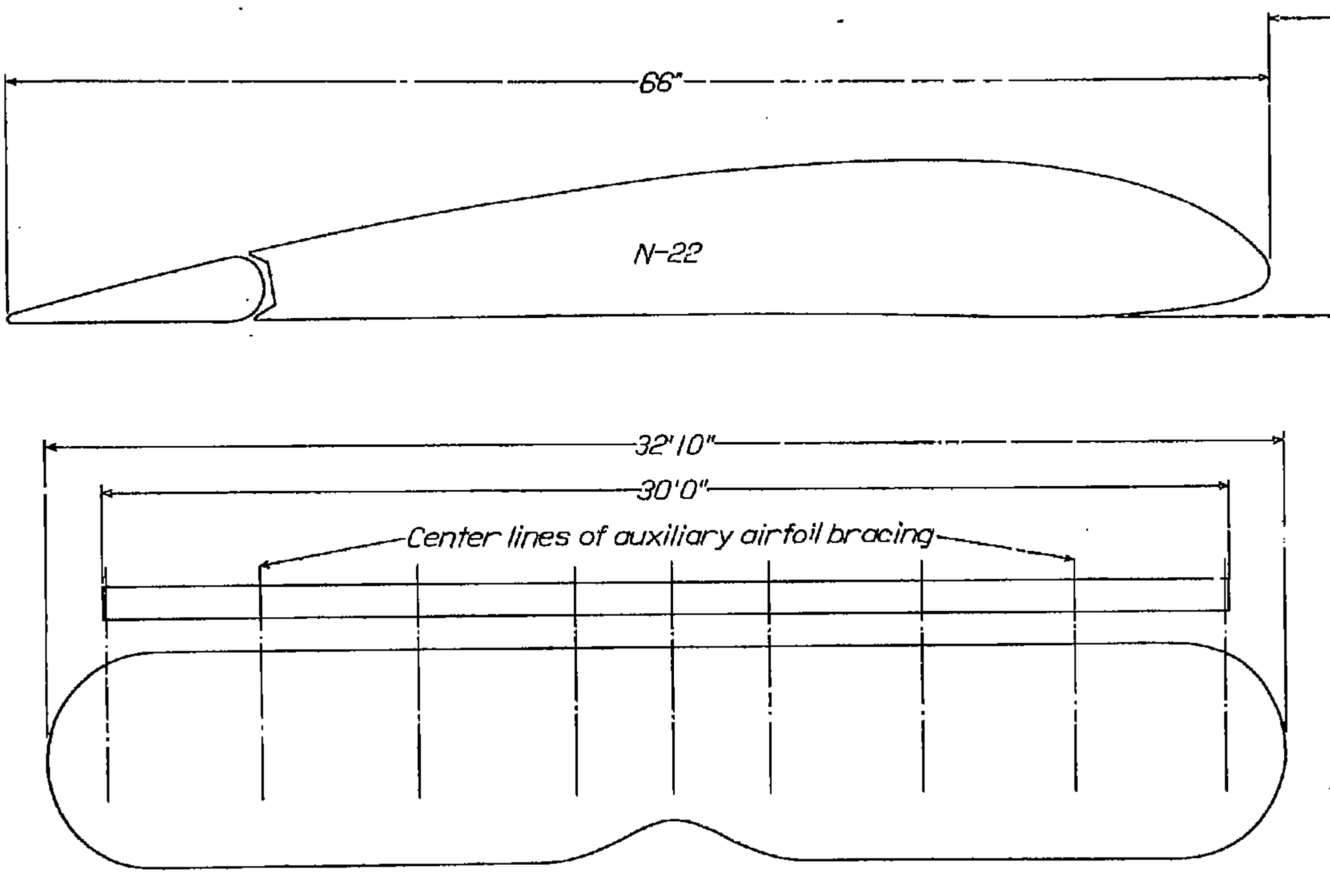

Ordinates of auxiliary airfoil, per cent chord

Sta.	Up'r	L'wr'
0	2.88	2.88
1.25	5.40	1.09
2.5	6.48	.65
5.0	8.02	.28
7.5	9.11	.08
10.0	9.96	.00
15.0	11.34	.12
20.0	12.29	.44
30.0	13.35	1.46
40.0	13.42	3.08
50.0	12.60	4.78
60.0	11.12	5.63
70.0	9.15	5.79
80.0	6.68	4.68
90.0	3.95	2.67
95.0	2.51	1.32
100.0	1.13	0.00

Fig. 1 The dimensions and location of the auxiliary airfoil installed on the Fairchild F-22 airplane.

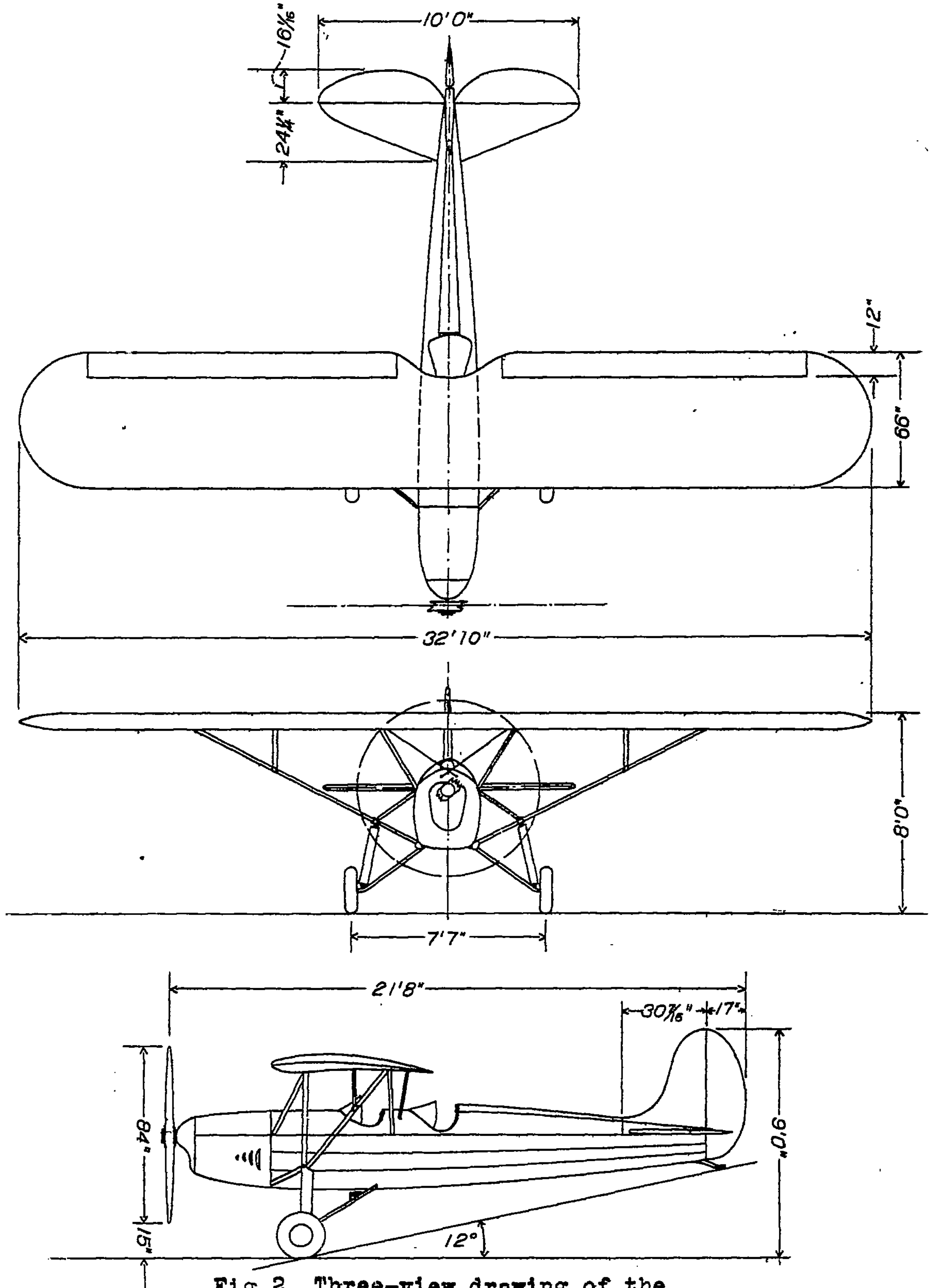

Fig. 2 Three-view drawing of the Fairchild F-22 airplane.

pole resistance

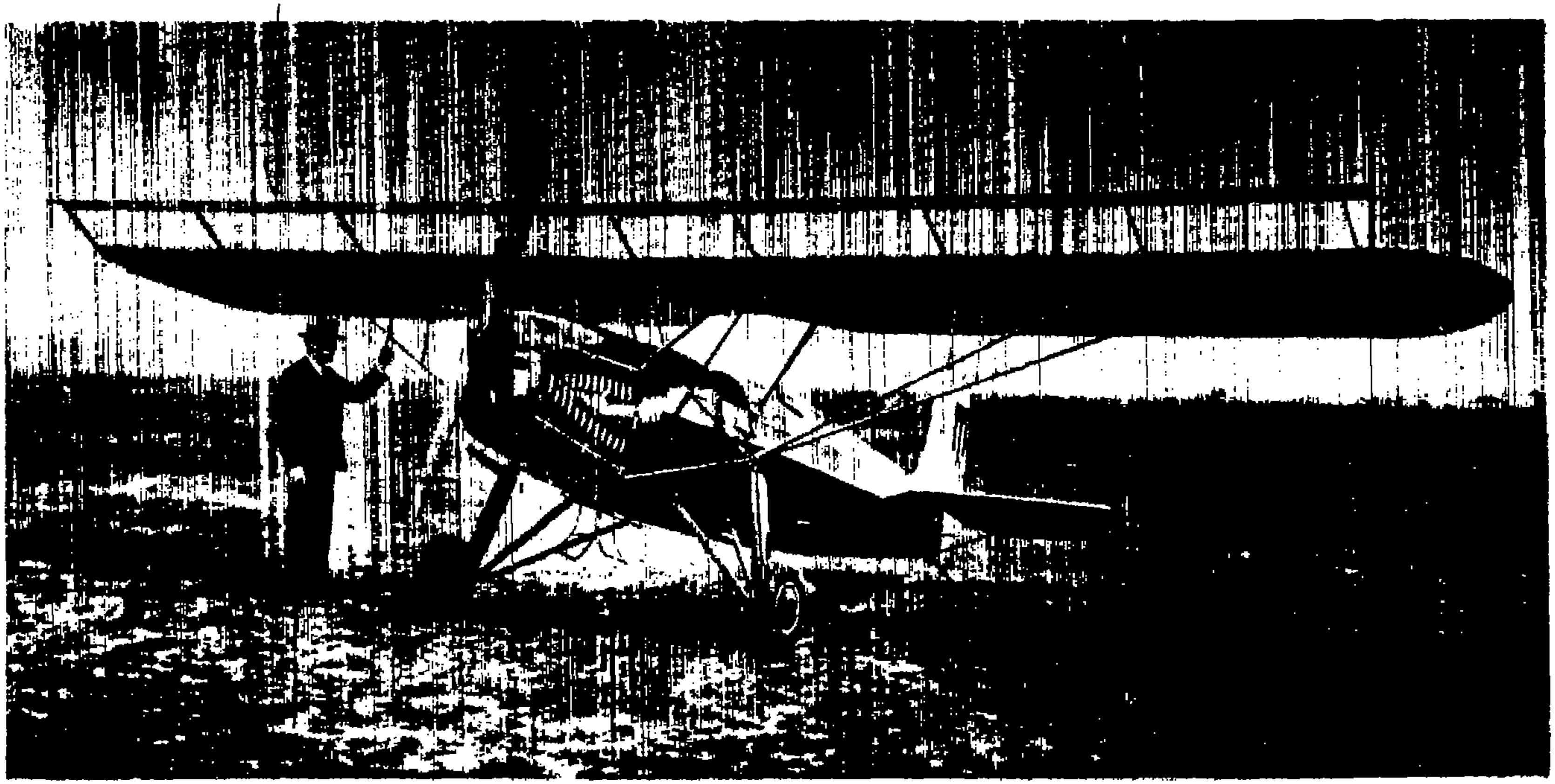

Figure 3.-Fairchild F-22 airplane with the auxiliary airfoil installed

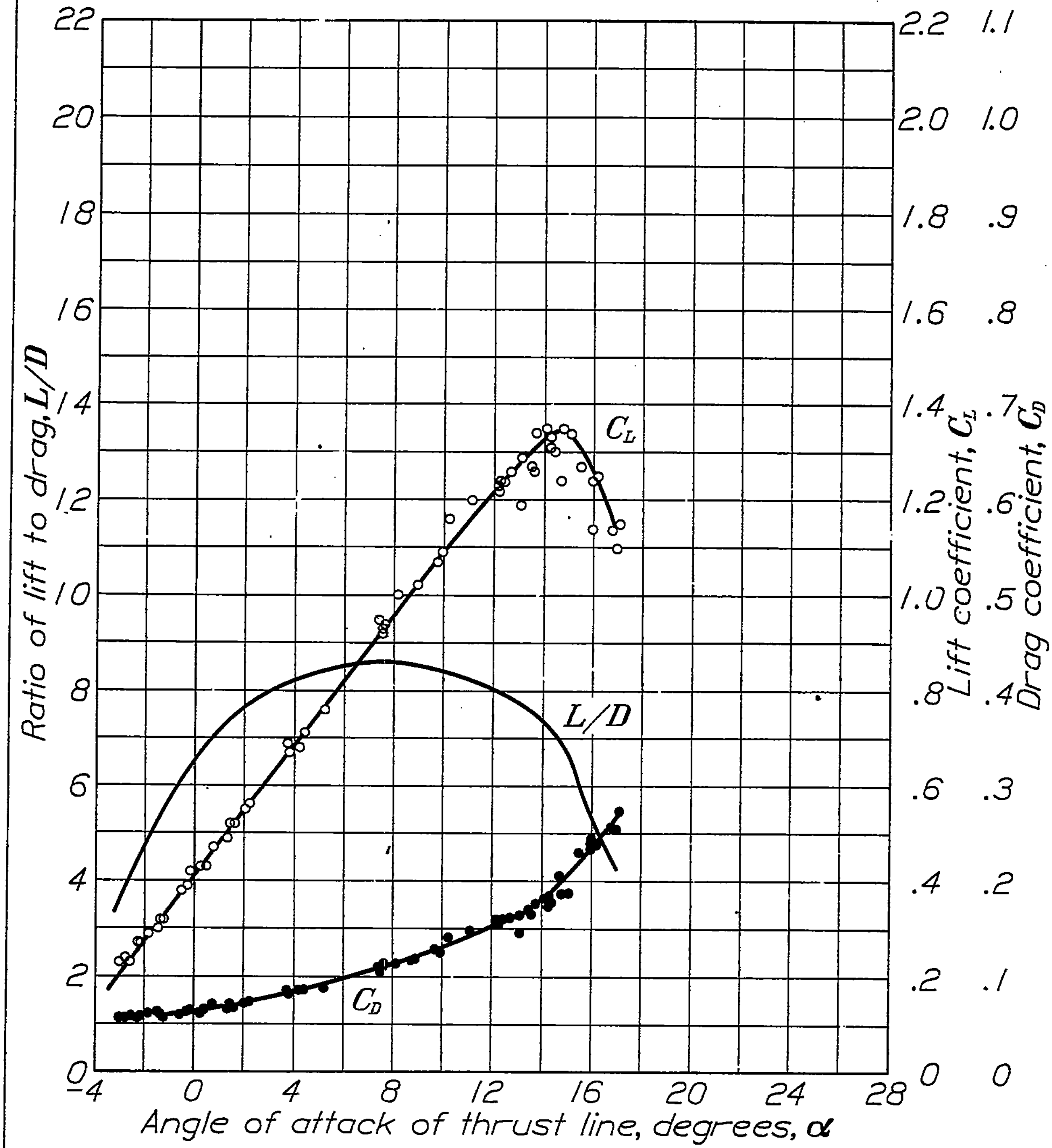

Fig.4 Aerodynamic characteristics of the Fairchild F-22 airplane, with N-22 wing section. Data from glide tests with propeller locked in vertical position. No correction for propeller drag.

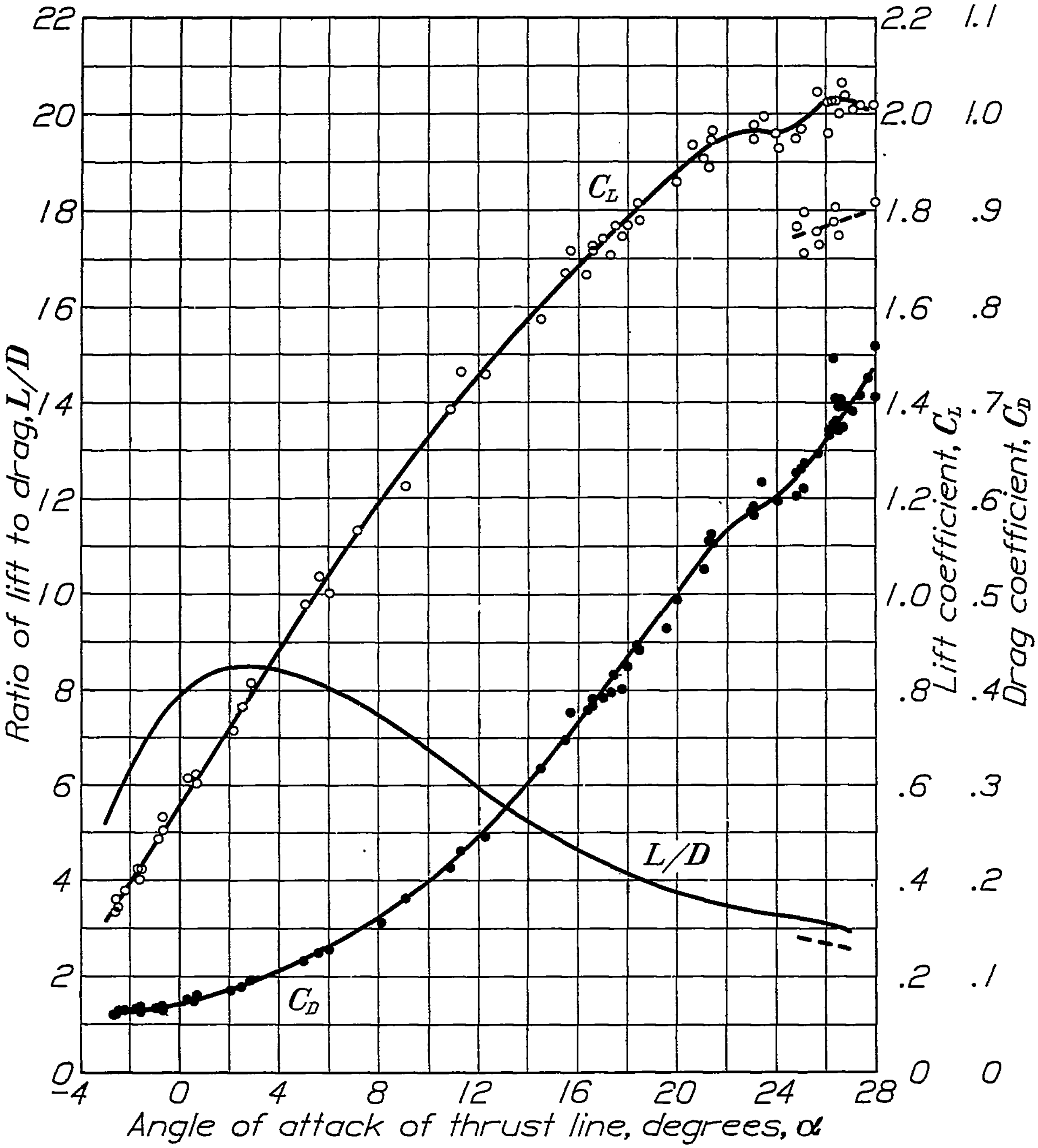

Fig. 5 Aerodynamic characteristics of the Fairchild F-22 airplane fitted with an auxiliary airfoil on an N-22 wing, based on main wing area only. Data from glide tests with propeller locked in vertical position. No correction for drag of propeller.

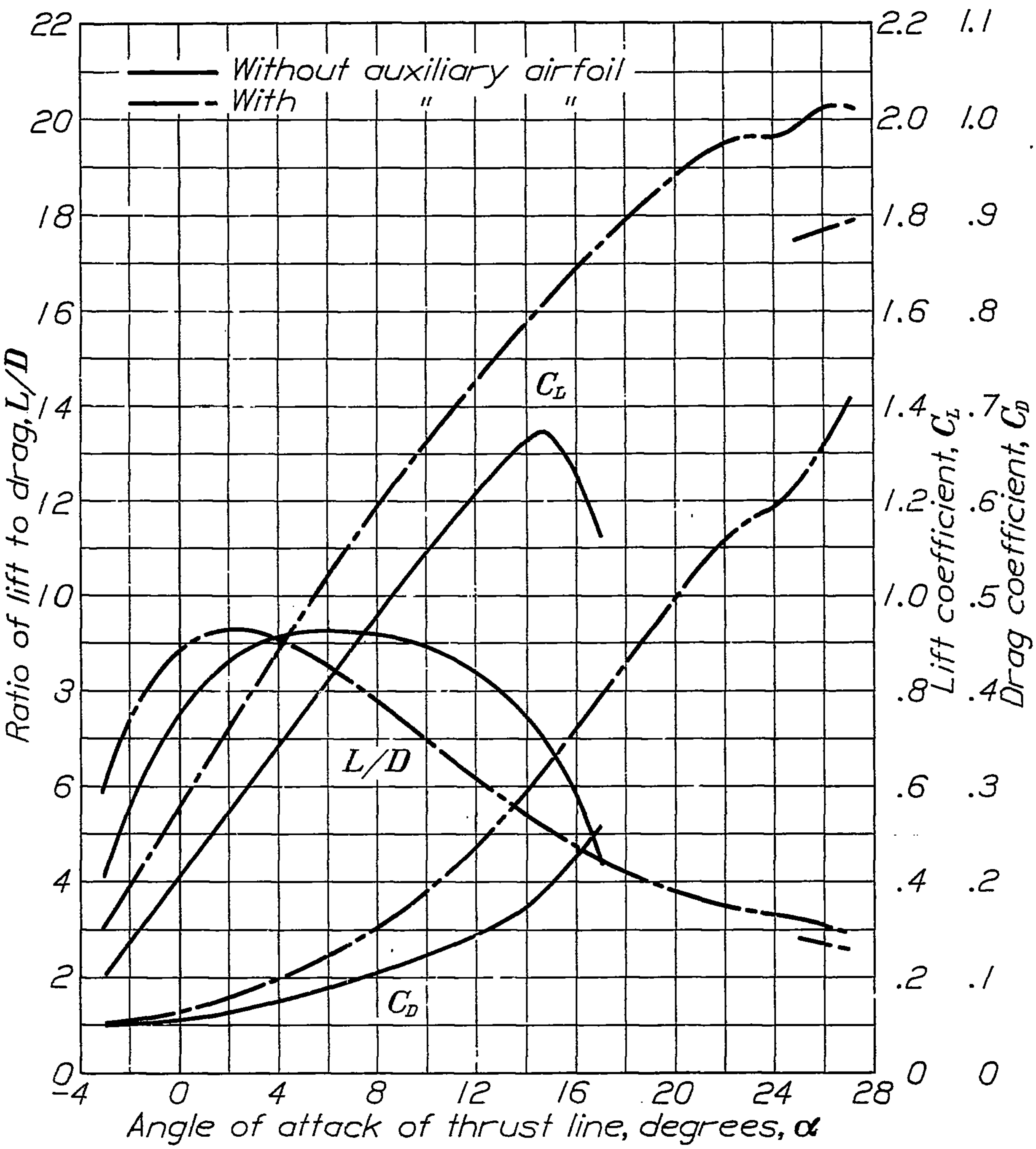

Fig.6 Comparative curves of the aerodynamic characteristics, based on the main wing area only, of the Fairchild F-22 airplane, with the original wing N-22 and with the auxiliary airfoil installed. Coefficients based on main wing area only. Corrections made for propeller drag.

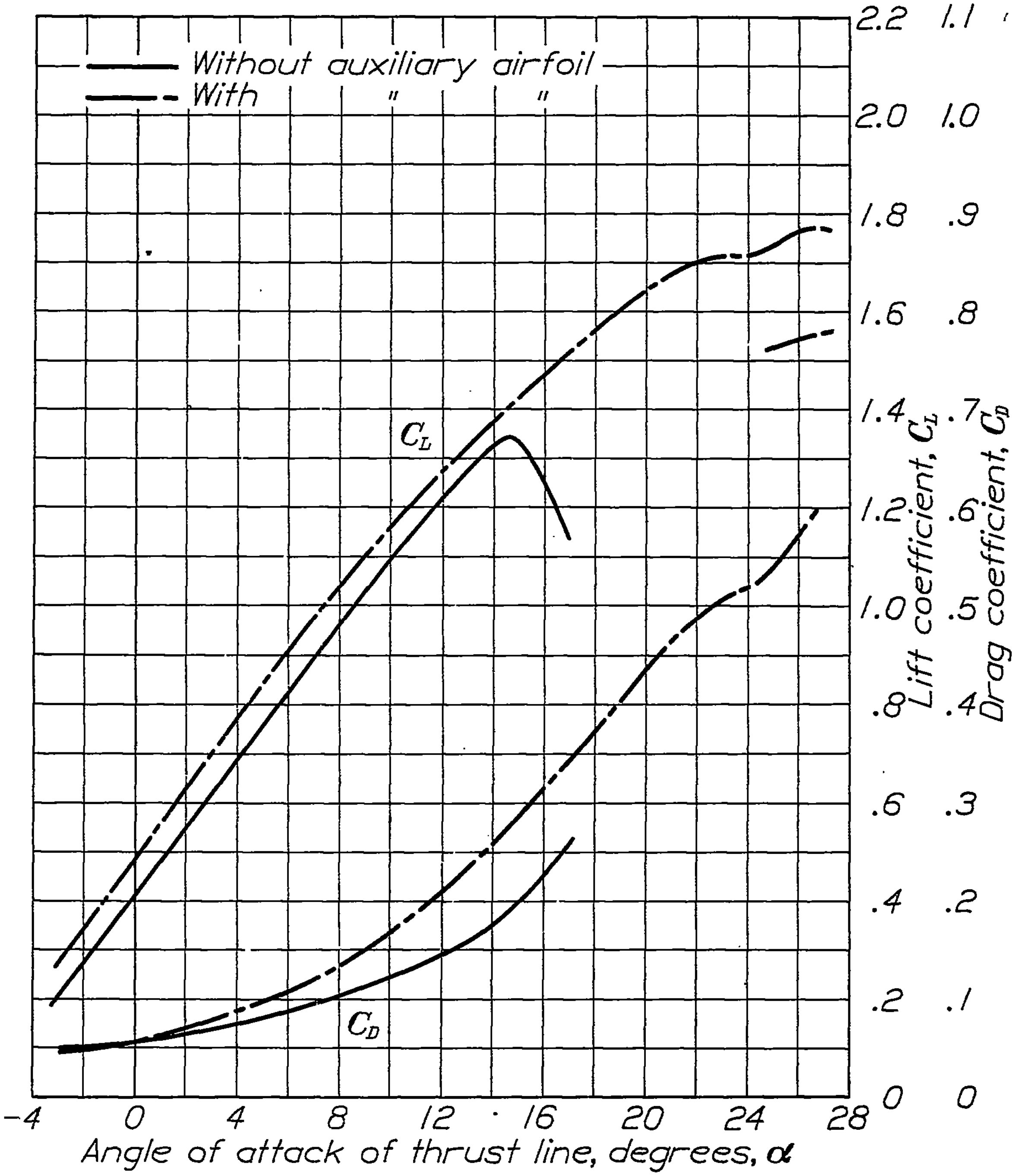

Fig. 7 Comparative curves of the aerodynamic characteristics, based on actual area, of the Fairchild F-22 airplane with the original wing N-22 and with the auxiliary airfoil installed. Coefficients based on the actual area for each condition. Corrections made for propeller drag.

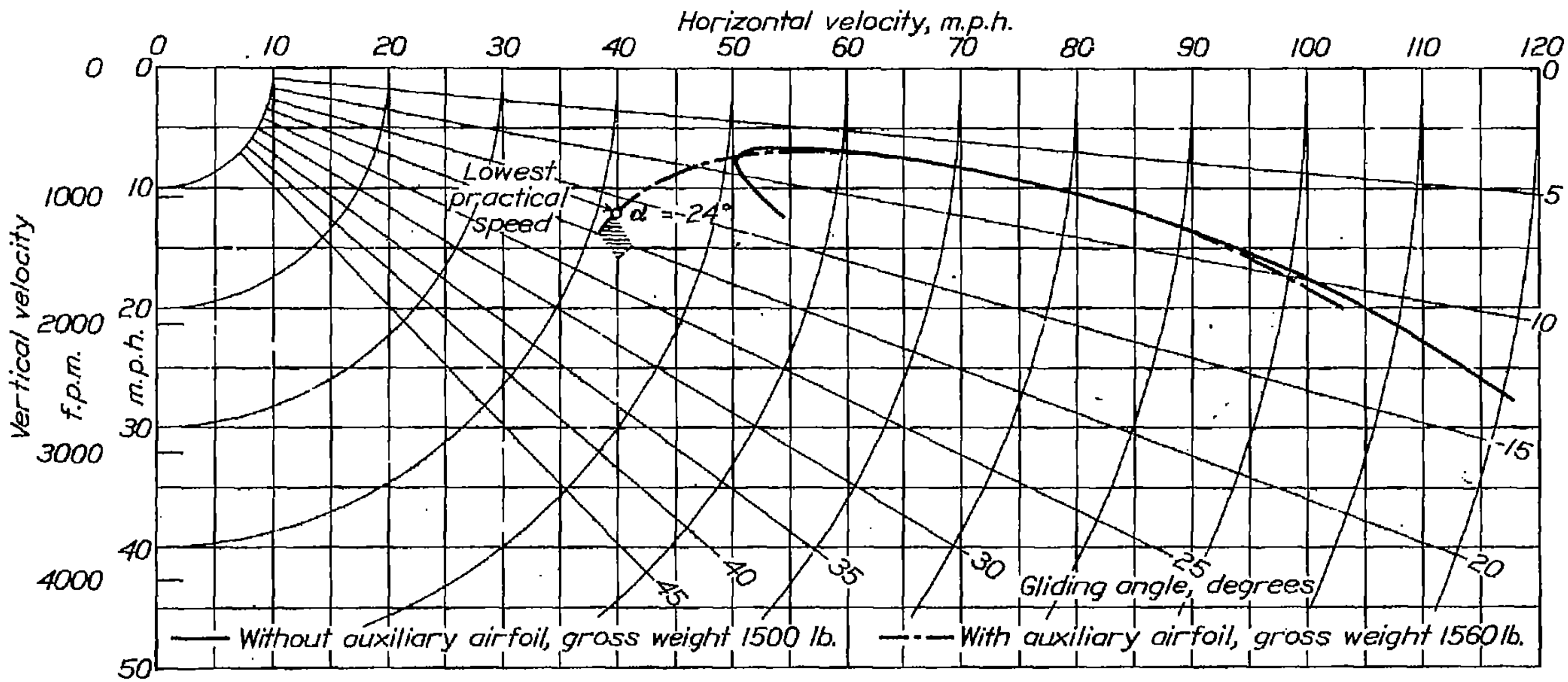

Fig. 8 Velocity diagrams for the Fairchild F-22 airplane with and without the auxiliary airfoil installed. N-22 airfoil section. Gliding performance. Propeller stopped in vertical position.

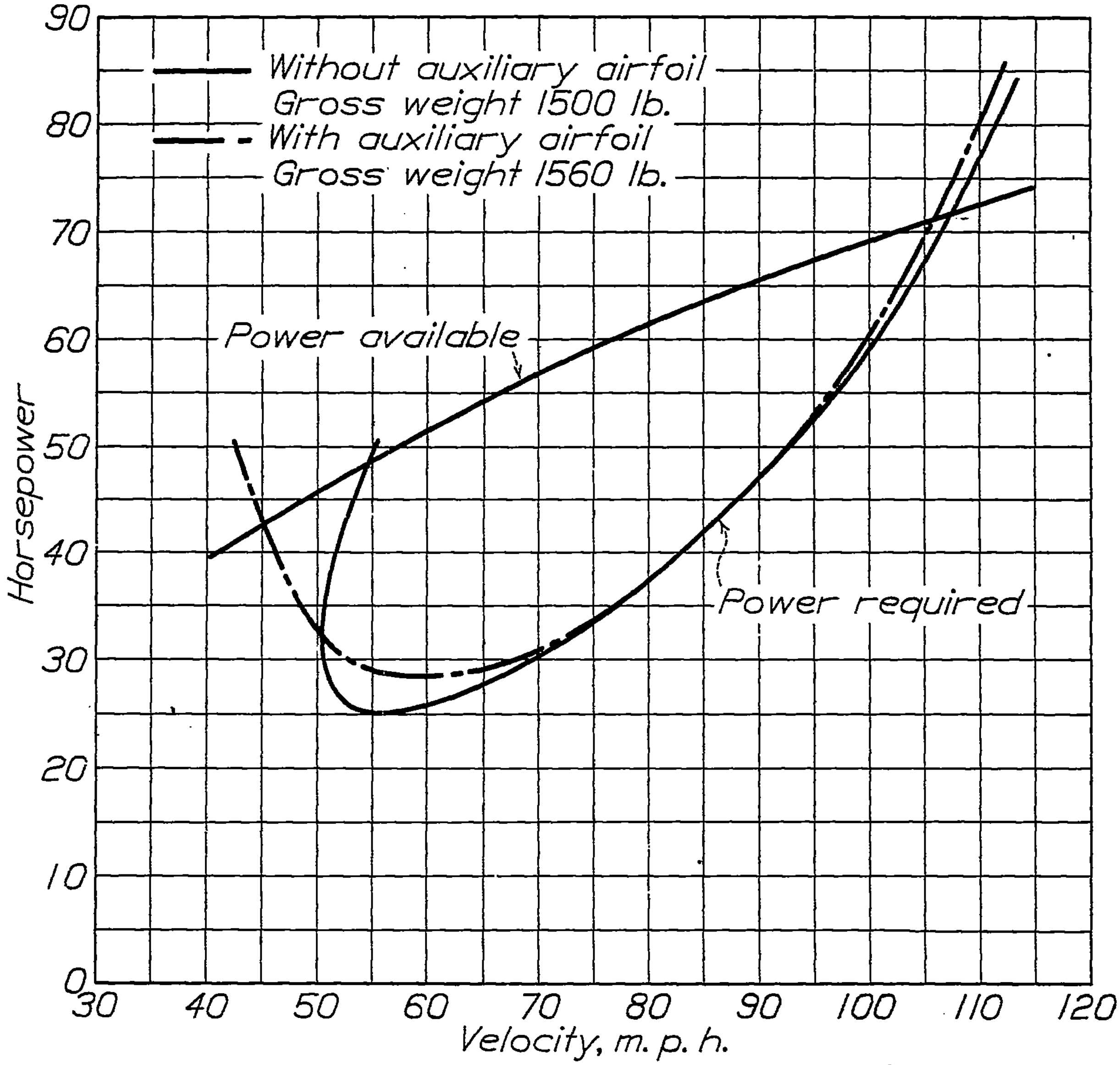

Fig. 9 Performance curves for the Fairchild F-22 airplane with and without the auxiliary airfoil installed. N-22 airfoil section.